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MIXING IN TURBULENT FLOW

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I. Summary

The technical report on the single heated jet confined in a duct has been completed, and will be distributed shortly. Work is progressing on the preparation of technical reports on dual isothermal jets with axes at an angle to one another, the electronic system of a hot-wire anemometer and studies of turbulent transport of heat in ducts, and the application of the Reichardt hypothesis to the transport of momentum and mass in coaxial gas jets.

The hot-wire anemometer has been moved to a new location in order to secure an oil-free air supply. Experimental studies on calibration coefficients of impact tubes are in progress. The computation of the extent of coalescence of droplets in turbulent free jets has been submitted to the Biological Department of the Army Chemical Corps for consideration. Experimental studies on the pneumatic thermometer and the high-velocity spray dryer are continuing.

The present contract expires on 31 December, 1951. Technical reports now in preparation will be issued as they are completed. A final summary report must necessarily await the completion of the technical reports.

The experimental work on the high-velocity spray dryer and the pneumatic thermometer will be carried to completion without additional support. When the experiments are complete, they will be covered in a technical report. The experiments involving impact tubes will be continued with support from the Office of Naval Research and the Flight Research Laboratory. When the studies covered in this proposal have been completed, they will be presented as a technical report to the Chemical Corps. The report covering the studies on coalescence of droplets awaits the decision of the Biological Division as to whether or not the recommended computation should be performed. If not, the technical report covering the work done will be prepared forthwith.

II. Background

The general objective of this program has been to investigate the mixing of fluid streams in turbulent jets. The free jet, the enclosed jet, and intersecting jet were the cases considered. The data resulting from fundamental studies were to be applied to atomization of liquids in gas streams and to processes involving the mixing of droplets and gases in jets and ducts, accompanied by the transport of momentum, heat, and mass.

III. Progress during the period covered by this report

a. Dual Isothermal Jets with Axes at an Angle to One Another

A technical report on this is in preparation .

b. Single Heated Jet Confined in A Duct

A technical report has been prepared, and will be distributed shortly.

c. Turbulent Transport of Heat in Ducts

The foremost problem impeding progress in this study has been the presence of oil in the air stream. An attempt was made to remove the oil by the use of high-pressure porous ceramic filters, and by low-pressure glass-batting air filters. Although the oil content was appreciably reduced by these methods, the air finally produced still contained too much oil to permit satisfactory operation of the hot wire anemometer. Moreover, because of the presence in the Air-Flow Laboratory of high-speed turbo-superchargers which operated at a prohibitively high noise level, it was decided to remove the anemometer and related equipment from the Air-Flow Laboratory, and to locate in the Projects Laboratory of the East Chemistry Building, on the University Campus in Urbana. A centrifugal blower was located and tested, and found to be a suitable air supply. The anemometer was dismantled, moved, and reassembled at its new site. It remains now to build the ducting and flow system needed for further experiments.

The technical report covering the work described in the Fourth Quarterly Progress Report is being prepared by R. W. Kunstman in conjunction with his doctoral dissertation. Further work with the anemometer will be reported in technical reports to the Office of Naval Research and the Flight Research Laboratory, which will support this research in the coming year.

d. High-Velocity Spray Dryer

The problems of instrumentation described in the Fourth Quarterly Progress Report have been attacked, and, it is believed, surmounted. The measurement of humidity was performed by an addition to the pneumatic thermometer (cf. section e-2, Instruments). The air stream was dried through a bed of magnesium perchlorate, an extremely effective desiccant; and the dried stream was then passed through a calibrated orifice. The humidity may be calculated by the difference in the volume of the moist and dried air streams.

The first drying runs, in which water droplets are evaporated, have recently been undertaken.

e. Instruments

1. The total head impact tube (Pitot Tube)

The experimental program concerned with the investigation into the calibration coefficients of impact tubes has been delayed by the unforeseen occurrence of leaks in the airflow system. Since these leaks were present in the part of the system between the flow meter and the equipment to be used in this investigation, and since the leaks were in heat exchange equipment which could neither be repaired nor removed from the line, it has been necessary to build a new flow meter, of the orifice type, and to locate it downstream of the leaks. This meter is now undergoing calibration. When this work is completed, it will be possible to return to the study on impact tubes.

In the interim, the literature search has been broadened and intensified, to determine whether the approach being taken in this research has ever been used before. In particular, recent studies are being evaluated.

The experimental program will be continued with the support previously mentioned. When that part of the research covered under this contract has been completed, a technical report will be prepared.

2. Dry Bulb Temperature Probe (Pneumatic Thermometer)

Repeated attempts to operate as critical oridices the several orifices of which the pneumatic thermometer is composed have failed because of lack of capacity of the pumps concerned. In order to avoid further loss of time and expense in securing a suitable vacuum pump, the pumps available have been operated submerged in ice, to prevent overheating and resultant severe damage. Since the orifices could not be operated at the critical pressure drop, it was necessary to calibrate each orifice. This was done by passing an air stream through one of a set of precision Flowraters, and then through the orifices.

Much of the experimental work during this period has been concerned with establishing the precise limits of accuracy permitted by the unavoidable errors in the apparatus. As an example of the nature of these errors, fourteen observations of manometers are required for the determination of each point. Taking into account the error inherent in each of these observations, a careful variance analysis shows that the probable error in any single observation of temperature is 3 percent. Since the readings will be in the region of 1000°R., the error will be about 30°F. out of about 600°F. However, these observational errors should be eliminated or materially reduced by the smoothing procedures to be employed in the course of operating the instrument. Although the value of any one observation may vary from the true reading by as much as 30°F., there should be far less variation in the mean value of ten such readings. The variation in the mean value has been found to be a

a function of the variation of the orifice coefficients with the gas flow rate. In evaluating the orifice coefficients, 219 separate runs were performed. They indicate that the maximum variation in orifice coefficients is of the order of 3 percent while the standard deviation of those coefficients from their mean value is 1.5 percent. Therefore, the standard deviation between successive readings of temperature obtained from the pneumatic thermometer should be not more than 15°F. in 1000°R., or 15°F. in about 600°F. This is satisfactory precision for engineering studies.

The pneumatic thermometer was further complicated by being modified in order to provide a humidity measurement. A third orifice was added to the line. Thoroughly desiccated air is passed through this last orifice and metered, and its flow rate is compared with that through the second orifice; from these two flow rates, the humidity of the gas flowing through the second orifice may be computed.

Barring unforeseen difficulties, the pneumatic thermometer may be used with reasonable assurance of accuracy within the limits specified.

f. Theoretical Program

The problem of coalescence of droplets in a turbulent jet was submitted to three computation laboratories, in order that estimates might be made of the cost of computing the solution. The laboratories were the Differential Analyzer Laboratory of the University of Pennsylvania, the Punched-Card Digital Computer Laboratory of the Department of Chemical Engineering at the Pennsylvania State College, and the Computer Laboratory of the National Bureau of Standards. The last named group has submitted as an estimate $5,000, while neither of the other groups has as yet been able to decide on the probable expense. Since the funds assigned to this contract are virtually exhausted, the matter of the computation has been turned over to the Biological Department together with all information necessary for the solution.

In the event that the Department prefers not to go ahead with the computation at this time, a technical report on the coalescence of droplets in turbulent jets will be prepared, in which the equations will be presented in their final form, together with all information necessary for the solution.

The extension of the Reichardt hypothesis to the flux of momentum and mass in the case of a jet issuing into a stream flowing in a duct has been completed. A technical report on this subject is in the last stages of preparation, and should be issued before the end of January, 1952.

IV. Personnel

The project has been under the supervision of Dr. Arnold Kivnick on a full-time basis; Professor H. F. Johnstone has replaced Professor E. W. Comings in the position of overall direction. During the period covered in this report, C. L. Coldren was employed on a half-time basis, on the high-velocity spray dryer. J. E. Romano worked on the hot-wire anemometer, and R. D. Danielson on the impact-tube studies; neither of these received compensation from the contract.